Extraction of clay mineral alteration zone in eastern Mongolia using JERS-1 data

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Abstract: The Metal Mining Agency of Japan has been empowered for the examination and evaluation of effectiveness of JERS-1 data since 1993. The eastern Mongolia was selected as a case of semi-arid area for the evaluation. The object area is located in the eastern part of the Gobi Desert spreading out from south of Mongolia, close to the border with China. Ilkh-Shankhai, Shütteen and Serven-Sukhait are known for presence of porphyry copper type mineralization formed by small granitic intrusive rocks. JERS-1 OPS (Optical Sensor) with some conservative technique of remote sensing was applied to identify the mineralization zone in this area. The findings of this study are as follows: (1) Based on the interpretation of color composite image (BGR =128), the silification zone around the Shütteen mineralization zone has been identified by peculiar bright red brown color. This spectrum anomaly suggests that the minerals having absorption in band 1 and band 2, such as iron oxide, are distributed on the surface of the area. Photogeologically, this spectrum anomaly zone is interpreted as topographically high elevation area, and erosion resistivity is inferred to be extremely high as compared to circumferential rocks. These results agree with existing information that iron-silisified rock is distributed over the center of the mineralization zone. (2) There is the possibility that mineralization is distributed over the Ulgen area, because spectrum anomaly of the Shütteen area is very similar to that of the Ulgen area.

1. Introduction

The Ministry of International Trade and Industry has been entrusting a technology development research for mineral exploration to the Metal Mining Agency of Japan (MMAJ) since 1993. As a part of this research, the MMAJ has been empowered for the examination and evaluation of effectiveness of two types of techniques, spectrum analysis and lineament analysis, in order to utilize remote sensing data mainly for mineral exploration. From 1993, the MMAJ started the study of mineral exploration for arid area, semi-arid area, vegetated and rain forest area based on technology developments of the agency, using data of the first Japanese earth resource satellite (JERS-1), which was launched in February, 1992. The basic purpose of this study is to apply some conservative technique of remote sensing to JERS-1 OPS (Optical Sensor) and SAR (Synthetic Aperture Radar) data and evaluate quality of the data. Fourteen areas were nominated in the whole world during 1993-95 as test area for this study, and the effectiveness evaluation to mineral exploration of each sensor was carried out. In this study, the eastern Mongolia was selected as a case of semi-arid area. This paper outlines the study conducted from 1993 to 1995.

2. The study area and geological setting

The object area is located in the eastern part of the Gobi Desert spreading out from south of Mongolia, close to the border with China, and ranges from latitude 43 degrees N 30 minutes to latitude 44 degrees N 10 minutes and from longitude 105 degrees E 30 minutes to longitude. 109 E 00 minutes (Fig. 1), approximately. A portion of the Palaeo Tethys Sea spread out widely to the position of current Mongolia orogenic belt from the Paleozoic era. In the north side of this sea, there was a continental plate, whose center was the Siberia block, and the ocean plate sank for this continental plate toward north. In the south side also, there was a continental plate uniting the blocks such as Sino-Korean, Tarim, Breya and

Keywords: JERS-1, Gobi, Shütteen, Ilkh-Shankhai, Serven-Sukhait, Mongolia
the ocean plate sank also for this continental plate. The basins of Junggar and Tsaidam, located in the west of basement at present, are so-called micro continents. Mongolia orogenic belt is an accretional prism added by the sinking of ocean plate below the Siberian Plate, and is composed mainly of ophiolite, high pressure type metamorphic rock and island arc volcanic rocks. Addition or unions of the continents are inferred to involve island arc itself in addition to the ocean earth crust and sediments (Metal Mining Agency of Japan 1991). The Tsagaan-Suvraga area is located in a place sandwiched between the two subduction zones mentioned above, and the direction of the major structure orients northeast-southwest, which is parallel to the subduction zone. Cretaceous non-marine sedimentary basin extends to the same direction, and is broadly covered by the clastic sediments (Fig. 2).
Extraction of alteration zone Mongolia using JERS-1 (Ooka et al.)

LEGEND

Rock Types

- Grey Sand and Pebble
- Redbed - Terrigenous deposits - Carbonate rocks
- Molasse (Marine and Continental)
- Terrigenous (including Greywacke, Flysh and Tuff)
- Olistostrome
- Jasper - Silica deposits - Terrigenous deposits
- Greenshale with Black shale
- Metabasaltic Greenrock
- Carbonate-quartzite with Amphibolite and Gneiss
- Basalt - Basaltic andesite - Andesite
- Andesite - Dacite - Rhyolite
- Dacite - Rhyolite
- Basalt - Trachybasalt - Trachyandesite
- Trachyandesite - Andesite - Rhyolite - Trachyryholite
- K-alkali lava with Carbonatite
- Contrasting volcanics
- Granodiorite - Granite
- Granite - Leucogranite with Granosyenite
- Monzonite - Syenite-Granosyenite
- Alkaligranite with Syenite
- Ultrabasic and Gabbro

Geologic Age

- Q: Quaternary
- K: Cretaceous
- J: Jurassic
- P: Permian
- C: Carboniferous
- D: Devonian
- S: Silurian

Others

- Fault
- Study Area

Fig. 2 Geologic Map of Study Area
The investigated area of Ikh-Shankhai, Shitteen and Serven-Suhait are underlain chiefly by porphyry copper type mineralization formed by small granitic intrusive rocks as host rock. Besides this mineralization, geochemical anomalies such as Mo, W, Mg, and as are distributed over the Ikh-Shangkhai area. Especially in Ikh-Shangkhai and Shitteen areas, silification zone including alunite and sericite is known to be accompanied with the mineralization.

3. Digital data sets and noise reduction technique for the study area

JERS-1 OPS 5 scene shown in the following was used for the analysis.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Path</th>
<th>Row</th>
<th>processed level</th>
<th>Observation date</th>
</tr>
</thead>
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<tr>
<td>OPS</td>
<td>126</td>
<td>227</td>
<td>2</td>
<td>1993/09/14</td>
</tr>
<tr>
<td>OPS</td>
<td>127</td>
<td>227</td>
<td>0, 2, 5</td>
<td>1993/10/29</td>
</tr>
<tr>
<td>OPS</td>
<td>128</td>
<td>227</td>
<td>2</td>
<td>1993/10/30</td>
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<tr>
<td>OPS</td>
<td>129</td>
<td>227</td>
<td>2</td>
<td>1992/07/04</td>
</tr>
<tr>
<td>OPS</td>
<td>130</td>
<td>227</td>
<td>2</td>
<td>1992/07/05</td>
</tr>
</tbody>
</table>

The color composite mosaic image (BGR=123) made from these five scenes is shown in Fig. 3. These data were examined before processing and two noise problems were found. The Gaussian filter was applied to reduce or remove line noise in horizontal direction on VNIR (Visible and Near-Infrared Radiometer), and smoothing filter for comb-like shape noise on SWIR (Short Wavelength Infrared Radiometer) caused by difference of CCD response. Furthermore, geometric correction by GCP (Ground Control Point) using with band 3 as a reference for each band after filtering process was applied to correct band-to-band registration of SWIR data.

4. Spectrum Analysis

We tried some spectrum analysis using false color composite image, logarithmic residuals image and ratio image to extract alteration zone.

(1) False color composite image

As a result of having examined band combination to extract distribution of alteration zone, this research has revealed that the color composite image BGR = 128 excels in indicating known alteration zone with peculiar dark red color. This feature suggests that the spectrum anomaly is originating from iron oxide accompanied with silificated zone having absorption band from band 1 to band 2.

(2) Logarithmic residuals image

Generally, the data obtained by optical sensor did not indicate reflectance of the ground by dispersion/absorption from the atmosphere and influence of the topographic condition precisely. Therefore, Logarithmic residuals method was applied in this study. The method estimates reflectance spectral pattern of the surface. Multiplication factor, effect of suppositional topography, solar altitude etc. for reflectance were removed using geometrical mean, and emphasizing fluctuation of each data from average of all reflectance data.

(3) Band ratio image

Band ratio analysis is made for identification of iron-oxides using the ratio of band 2 and band 1, for kaolinite of band 5 and band 2, and for calcite and alunite the ratio of band 5 and band 8. The ratio value 1.5, which extracts distribution of alteration zone most adequately, is selected on the rule basis of trial and error. BGR are assigned the ratios 5/8, 5/9 and 2/1, respectively.

5. Results

5.1 Geologic interpretation

Fig. 4 shows false color composites image (Path 127/Row 227, BGR=128) extracting spectrum anomaly regarded as mineralized zone, and Fig. 5 and Table 1 show interpretation of geology from the same image. The silicification zone around the Shitteen mineralized area, located in north-west side of the image, was extracted as peculiar bright red brown color patch in Fig. 4. From this spectrum anomaly, we inferred that minerals characterized by absorption pattern in band 1 to band 2 of OPS range, such as iron oxides, are distributed on the surface of the mineralized zone. Photogeologically, this spectrum anomaly is confirmed as topographically elevated area, and it is estimated to have extremely high erosion resistivity as compared to surrounding rocks. These interpretations agree with findings provided by previous studies that ferrous silificated rock is distributed over the center of the mineralized zone. Similar spectrum anomaly is also extracted in the Ùlegen area of south-east part in the image. This indicates a possibility that similar type of mineralized zone is distributed over the area.

5.2 Spectral analysis

Spectral analyses were applied to analyze the images of Ikh-Shankhai, Shitteen, Serven-Suhait (these three are known mineralized zones), and Ùlegen-West. The location of each sub-scene data is shown in Fig. 3.

5.2.1 Ikh-Shankhai area

The Ikh-Shankhai mineralization area is located at longitude 106°00'00"E, and latitude 43°40'20"N. The mineralized area is about 1,100 meters above mean sea level and consists of small hills with the altitude difference of 100 to 200 meters. The ore deposit is a porphyry copper type deposit with primary chalcopyrite accompanied granodiorite porphyry. Dissemination type copper mineralization is recognized, and the scale of the deposit is: maximum extension 1500 meters, width 5-10 meters. Wall-rock is composed of Late Carboniferous andesite, tuff/siltstone, and these are
Fig. 3 Mosaic Image of JERS-1 OPS. Stüsen is expresses as Shuten, Ikh-Shankhai as Ih-Shanhai, and Ülgen as Ülegen in this figure.
Fig. 4  JERS-1 OPS Color Composite Image (Path 127/Row 227). Sűteen is expresses as Shutenand and Ulgen West as Ulgen West in this figure.
Fig. 5 Image Interpretation Map of JERS-1 OPS (Path 127/Row 227)
intruded by Carboniferous-Permian granite, granodiorite and granodiorite porphyry. Silification, kaolinitization, carbonization, potassium feldspar alteration, argillization and tourmalization are recognized in mineralization zone, and chalcopyrite alteration is accompanied with all alterations. False color composite image (BGR = 123), logarithmic residuals image (BGR = 357) and ratio image (BGR = 5/8, 5/7, 2/1) of the Ikh-Shankhai area are shown in Fig. 6.

False color composite image: Since each band of SWIR image of Path 130/Row 227 was not able to improve image quality enough by the filtering, BGR = 123 was used for color composite image. A white colored zone in the center of this image and its northeast extension, are known as silicified zone with Kaolinite. From this image, pixels indicating a very high reflection in VNIR range are inferred to be distributed over the alteration zone. And same stratified white colored zone is recognized in addition to the alteration zone.

Logarithmic residuals image: A white portion in composite image shows cyan color in logarithmic residuals image. This result suggested that clay mineral or carbonate minerals with absorption in band 7 are distributed over the area.

Band ratio image: The point, which is known to be a distribution of silification, and in the area of which appears white in false color composite image, and cyan in logarithmic residuals image, indicates cyan in color, and both ratio 5/7 and 5/8 show spectrum anomaly. On the other hand, the area except alteration zone, which is extracted by anomalies in color composite and logarithmic residuals images, is distinguished from mineralization zone because it shows no anomaly or only anomaly of 5/7. Among alteration minerals distributed over the mineralized zone mentioned above, anomaly 5/7 shows kaolinite and 5/8 carbonate minerals, and mineralized zone is identical with the zone when both anomalies are overlapped.

5.2.2 Sh têteen area
The Sh têteen mineralization area is located at longitude 107°21′15′′ E, and latitude 43°36′25″ N. Mineralized area is about 1,100 meters above sea level, and consists of small hills with the altitude difference of 100 to 200 meters, and is very similar to the Ikh-Shankhai area. The ore deposit is of porphyry copper type with primary chalcopyrite and is accompanied by Late Carboniferous to Early Permian granodiorite. The deposit is distributed along N–S direction with 2 km width and 8 km length in silicified or argillization zone. Wall-rock is composed of Early Carboniferous eugeosynclinal sedimentary rocks, Late Carboniferous-Early Permian intermediate-acidic volcanic effusive rocks, diorite, granite, syenite, granodiorite, porphyrite and aplite etc.. Silification, alunization, diaspore, pyrophyllite, sericite, tourmaline, propylite, potassium feldspar etc. have been recognized in mineralized zone. Sh têteen mineralization area, located inside a clear ring structure with diameter about 15 km, has been identified from the image (Fig. 4). Color composite image (BGR = 138), logarithmic residuals image (BGR = 178) and ratio image (BGR = 5/8, 5/7, 2/1) of Sh têteen area are shown in Fig. 7.

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Table 1 List of Geologic Units in Interpretation Map

<table>
<thead>
<tr>
<th>No.</th>
<th>Units</th>
<th>Color</th>
<th>Tone</th>
<th>Drainage</th>
<th>Geomorphologic aspects</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pattern</td>
<td>Density</td>
<td>Resistance</td>
</tr>
<tr>
<td>1</td>
<td>Q1</td>
<td>white, pale brown</td>
<td>light</td>
<td>contorted</td>
<td>coarse</td>
<td>very low</td>
</tr>
<tr>
<td>2</td>
<td>Q2</td>
<td>pale brown to gray</td>
<td>dark to light</td>
<td>radial</td>
<td>coarse to dense</td>
<td>low</td>
</tr>
<tr>
<td>3</td>
<td>K3</td>
<td>pinkish gray</td>
<td>moderate to light</td>
<td>-</td>
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<td>moderate</td>
</tr>
<tr>
<td>4</td>
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<td>moderate to dark</td>
<td>-</td>
<td>very low</td>
<td>moderate</td>
</tr>
<tr>
<td>5</td>
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<td>moderate to dark</td>
<td>dendrit</td>
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<td>moderate</td>
</tr>
<tr>
<td>6</td>
<td>J3</td>
<td>bluish gray</td>
<td>dark</td>
<td>-</td>
<td>very low</td>
<td>low</td>
</tr>
<tr>
<td>7</td>
<td>J2</td>
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<td>very dark</td>
<td>trellis</td>
<td>high</td>
<td>high</td>
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<tr>
<td>8</td>
<td>J1</td>
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<td>light</td>
<td>-</td>
<td>very low</td>
<td>moderate</td>
</tr>
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<td>9</td>
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<tr>
<td>10</td>
<td>C2</td>
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<td>low</td>
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<tr>
<td>11</td>
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<tr>
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<td>13</td>
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<td>14</td>
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<td>moderate</td>
</tr>
<tr>
<td>15</td>
<td>TA</td>
<td>reddish brown</td>
<td>moderate</td>
<td>-</td>
<td>very low</td>
<td>very high</td>
</tr>
</tbody>
</table>
Extraction of alteration zone Mongolia using JERS-1 (Ooka et al.)

Fig. 6 Results of Spectral Analysis in Ikh-Shankhai Area
Fig. 7  Results of Spectral Analysis in Shüteen Area
False color composite image: A hill corresponding to light red-brown color has been recognized at the center of this image. The hill is the distribution area of alteration zone leading mainly to silicification. Judging from the color tone, the band 1 and 3 are inferred to have absorption for silisification.

Logarithmic residuals image: In this image, alteration zone appears yellow to red in color, however, the change of this color is interpreted as influence of the topography. In other words, the high reflection part of albedo appears a red color at southeast side slope of ridge, and the low reflection part of albedo appears a yellow color at northwest side slope. This result indicates that the conversion to apparent reflectance by logarithmic residuals is incomplete. However, it clearly shows yellowish color, indicating alteration zone. Thus, it can be assumed that iron oxide minerals, which show absorption in band 1, are broadly distributed over the alteration zone.

Band ratio image: Only anomaly of ratio 2/1 that indicates distribution of iron oxide was extracted in alteration zone, which is considered to be a silicifed zone by band ratio image. Anomalies of ratio 5/7 and 5/8 indicate the distribution of clay minerals, carbonate minerals, alunite etc. However, the anomalies are not extracted in this image. Green color pixel showing 5/7 anomaly is distributed mainly on the front of the hill, which is formed by mineralized zone. Since this greenish color corresponds to the place of prevalent talus, it doesn’t seem to indicate mineralization. The above observations suggest that surface of the ground in this area is widely covered by iron oxide minerals. Stereo pair image by OPS level 5 data was made about mineralized zone of the Shitteen area (Fig. 8). The mineralized zone of the Shitteen area form erosional remnant of resistant block can be distinctly recognized with this image. A ring structure with approximately 15 km diameter surrounding the Shitteen mineralized area is formed by topography of a series of gentle ridge, and the north side of ring structure is cut by east-west trending lineament. And it can also be distinguished from the bird’s-eye view image, which is a color composite image (BGR = 138), and from the digital terrain model by stereo pair image, that Shitteen mineralized area showing red brown color forms the hill topography.

5.2.3 Serven-Sukhait area
The Tsagaan-Suvarga ore deposit system in a narrow sense is located in the eastern part of the Tsagaan-Suvarga area, whose center is approximately at longitude 108°20’47” E, and latitude 43°51’56” N. The Tsagaan-Suvarga deposit group has formed from nine ore bodies distributed over an area of 2×3.5 km², and the first ore body of the group whose grade and reserves are most superior, is called the Serven Sukhait deposit. Mineralized area consists of small hills generally ranging in altitude from 900 to 1,100 meters and waste-filled valleys. The ore deposit types are porphyry copper and molybdenum deposits. Primary minerals consist of chalcopyrite and bornite. These minerals replace mafic minerals in syenite or filled up micro fractures. Molybdenite fills up mainly micro fracture with film-like form. Some quartz veinlets accompanied with these minerals has been recognized. A few sphalerite, hematite and chalcopyrite are also observable. The characteristic of the ore is that it is totally poor in pyrite. Secondary enrichment is feeble, but is rich in primary minerals. Stockwork vein is divided into two types, quartz-sulfide minerals and quartz-sericite-sulfide minerals. The tendency that grade of molybdenite improves with deeper level below ground, is recognized in Serven-Sukhait deposit. Malachite, chalcocite and covellite are observed as secondary minerals. Wall-rock is Late Carboniferous-Early Permian quartz monzonite which intrudes sedimentary rocks of Middle-Upper Devonian and Lower Carboniferous. Each ore body is extended along NE-SW, and is controlled NE trends’ fault formed before mineralization, and is then silt by NW trend’s fault after mineralization. Weak argilization with white color and broad potassium feldspar alteration are recognized along the hanging wall of the Serven-Sukhait deposit. Color composite image (BGR = 123), Logarithmic residuals image (BGR = 178) and ratio image (R = 2/1) are shown in Fig. 9.

False color composite image: The block with white or light gray color in the center of the image, is the distribution of quartz monzonite which embeds Tsagaan-Suvarga deposit group. Because of contrast with the sedimentary rocks, it can be clearly discriminated between host and sedimentary rocks by the combination of VNIR band’s color composite only.

Logarithmic residuals image: The distribution of quartz monzonite is discriminated as red or yellow and green color on the image. From the band combination, yellow color is interpreted as surface material having absorption in band 1, and it suggests the distribution of iron oxide. Greenish color is the effect of absorption in band 1 and 8, and it indicates the distribution of iron oxides and clay or carbonate minerals. However, the possibility that these results suggest mineralization zone is low, because the characteristic color of mineralization is not recognized at the Serven-Sukhait deposit. The difference in distribution of the surface materials such as clastics may lead to the difference in color tone, because red to yellow colors indicate hill area and greenish color shows plain area.

Band ratio image: Because band 5 and 7 can not be used due to noise in image of this area, analysis was made only about band ratio 2/1. The anomaly of
Fig. 8  a JERS-1 OPS Stereo Pair Image in Shiiteen Area  
b Birds-eye View of the Shiiteen Prospect
Fig. 9 Results of Spectral Analysis in Serven-Sukhait Area
Fig. 10  Results of Spectral Analysis in Ulgen-West Area
band 2/1 is scattered in the area of quartz monzonite, however, the anomaly was not extracted as Serven-Sukhait deposits. And the distribution of 2/1 anomaly suggests a possibility related to faults, because a tendency distributed along lineament in quartz monzonite has been recognized. The alteration minerals distributed over the area, which can be extracted with OPS, are white clay minerals, however, the distribution is not possible to be extracted by spectrum analysis, because size of the deposits is small and alteration weak.

5.2.4 Ulgen-West area

The Ulgen-West area was extracted as the newly promising area which showed spectrum anomaly same as the Shitteen mineralization area, by color composite image of OPS (BGR=128). The color composite image of the Ulgen-West area (BGR=138), logarithmic residuals image (BGR=178) and the ratio image (BGR=5/8, 5/7, 2/1) are shown in Fig. 10.

False color composite image: The red brown patch scatters in the center of the image. It can be assumed that the mineral having absorption in band 1 and 3 are distributed over the area, and it suggests that the same type of mineralization is taking place.

Logarithmic residuals image: The yellow color in the image is interpreted as the distribution of materials having absorption in band 1, and it suggests the distribution of iron oxide.

Band ratio image: Some red color was extracted from a spot area, which is located in the eastern side of the center of the image and two spot areas at approximately three kilometers south from the first spot. There is a large possibility that iron oxide zone has formed in these spots. However, the alteration zone is inferred to be rather small in size as compared to the Shitteen mineralization area according to the analysis.

6. Summary

The findings of this study are summarized as follows:
(1) Based on the interpretation of color composite image (BGR=128), the silicification zone around the Shitteen mineralization zone has been extracted as peculiar bright red brown in color. This spectrum anomaly suggests that the minerals having absorption in band 1 and 2, such as iron oxide, are distributed on the surface of the area. Photogeologically, this spectrum anomaly zone is interpreted as topographically high elevation area, and erosion resistivity is inferred to be extremely high as compared to circumferential rocks. These results agree with existing information that iron-silicified rock is distributed over the center of the mineralization zone.
(2) There is a possibility that mineralization is distributed over the Ulgen area, because spectrum anomaly of the Shitteen area is very similar to that of the Ulgen area.

Acknowledgments: This study is a part of the research projects on mineral exploration, which is conducted by Metal Mining Agency of Japan and Earth Resource Satellite Data Analysis Center. We would like to thank Satoshi Murao, GSJ, and members of remote sensing committee of the research projects for mineral exploration. Mining Division, Agency of Natural Resources and Energy of MITI, kindly gave us the permission to publish this research.

References


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JERS-1 データを用いたモンゴル東部における変質帯の抽出

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要 旨

金属鉱業事業団では平成5年度から通商産業省資源エネルギー庁の委託を受け、鉱物資源探査技術開発調査を実施しており、この一環としてモンゴル東部地域におけるJERS-1による変質帯抽出評価を行った。調査対象地域は、モンゴル国南部に広がるゴビ砂漠の東部。中国との国境付近に位置し、およそ北緯43度30分から北緯44度10分および東経105度30分から東経109度00分に広がる範囲であり、Ikh-Shankhai（イヒ・シンヤンハイ）地区、Shitteen（シュテン地区）、Serven-Sukhait（セルヴェン・スハイト）地区をはじめとして、各所に小規模な貫入花崗岩類を母岩として形成されたポーフィリーハッパー型の銅鉱亜軸などが分布する。

これらの地域においてJERS-1 OPS センサーデータによるフォールスカラー画像（BGR＝128）による判読を行った結果、シュテン鉱稜地周辺の珪化帯が、黒褐色で、赤褐色で、抽出された。このスペクトル異常により同変質帯の表面には酸化鉄などのOPS バンド1から2にかけて吸収バターンを示す鉱物が分布することが推定できる。また、この異常帯は地形的に突出していることが写真地質学的に判読され、周辺の岩石に比較して浸食抵抗が著しく高いものと推定される。これらの判読結果は同鉱稜地の中心部に含鉱珪化岩が分布という既存資料と一致する。また、同様の鉱稜を示すスペクトル異常が画像南東部のÜlgen（ウルゲン）地区においても抽出されるため同地区に珪化変質帯が分布する可能性があることがわかった。